Proactive and Predictive Strategies for Setting Oil Analysis Alarms and Limits

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Abstract: In oil analysis, well placed alarms and limits are like trip wires, alerting operators and technicians to an untoward or threatening condition. Oil analysis limits can vary considerably according to machine type, oil type, and reliability goals. This paper discusses four distinct types of limits and how they are applied to different machine and lubricant applications: goal-based limits, aging limits, rate-of-change limits, and statistical limits.

Keywords: Alarms; proactive; predictive; condition-based oil changes; limits; rate of change limits; contamination.

In the past, users of oil analysis have relied almost exclusively on the commercial laboratory to set and enunciate data alarms. This has put an unrealistic burden on the labs to understand information about user-equipment they have never seen. Likewise, the goals and objectives of the user with respect to reliability and maintenance may not be fully understood. Usually, this leaves the lab with no alternative other than to use standard default alarms. When these one-size-fits-all alarms are used, many of the opportunities and objectives of a modern condition-based maintenance program are missed.

In recent years, with the advent of sophisticated user-level oil analysis software, many site oil analysis technologists are taking responsibility for setting alarms and limits independent of the lab. The lab, in turn, is being asked to only deliver accurate and timely oil analysis results, leaving interpretation and exception reporting to the user. With the user being familiar with the lubricants, machines, historical problems, and general reliability goals, the most proper and effective limits can then be set. However, a critical ingredient is a sufficient level of training in oil analysis by the user.

What are Oil Analysis Alarms and Limits?: When plant-level oil analysis software is employed, one of the main benefits is the funneling down (or filtering) of the amount of data actually viewed and analyzed. This data reduction goal is essential and relates to the tactical goal of exception reporting, that is, the viewing of only the data that is out of compliance with acceptable trends or levels. All other data is held and managed in a database for future reference and use. The limits, when properly set, give confidence that conforming fluids are, in fact, okay and that non-conforming conditions have been caught proactively.

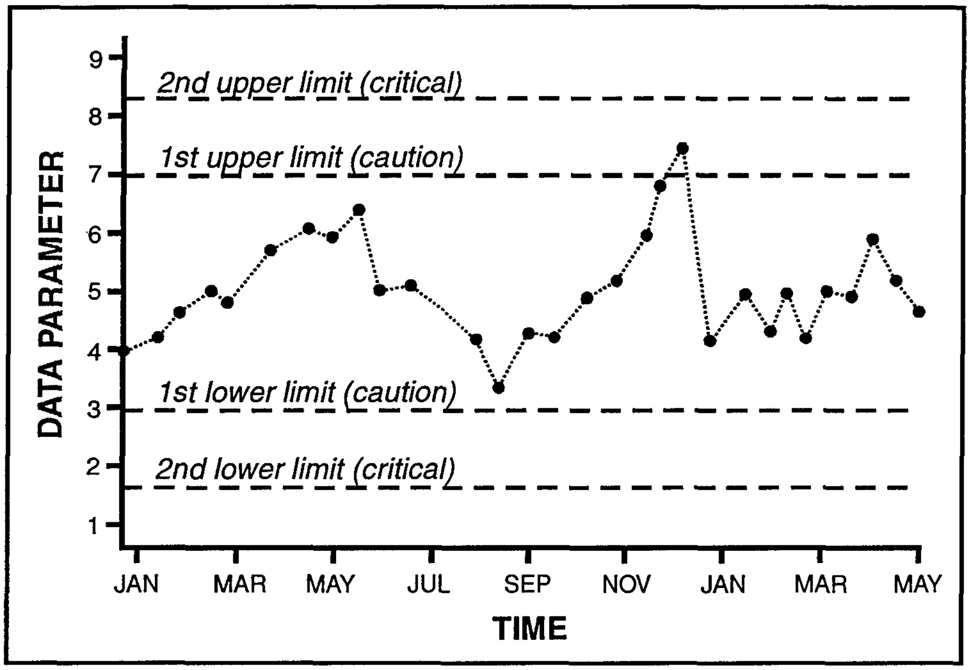


Figure 1
Illustration of Upper and Lower Oil Analysis Limits

Because the goals and expectations vary considerably from one organization to another these limits are best set by those charged with the responsibility of machine reliability and long fluid life. They are also influenced by machine and application specific considerations. For instance, where the gear box loads and duty cycle are low in one application, they may exceed rated levels in another. The availability of spares and standby equipment may influence the decision with equal magnitude. And, the age of the machine or lubricant may impact the placement of limits in certain cases.

Basically, a limit or alarm is a strategically placed "trip wire" that alerts you to an abnormal condition. Some data parameters have only upper limits such as particle counts or wear debris levels. A few data parameters apply a few lower limits like TBN, additive elements, flash point, and FTIR (additive). Other data parameters use both upper and lower limits. These might relate to important chemical and physical properties of the lubricant such its viscosity (see Figure 1). The computer trends the data and normally no alarm is reported as long as the limits are not exceeded. When an exception exists the

software is designed to alert and direct corrective action in response to the deleterious result. To insure maximum benefit from oil analysis, careful thought needs to go into the type of limit used and its setting.

Some Limits are More Proactive: Proactive limits are designed to alert users to abnormal machine conditions associated with root causes of machine and lubricant degradation. They are keyed to the proactive maintenance philosophy of setting targets (or standards) and managing the lubricant conditions to within the targets. A strategic premise is that these conditions are controlled to levels that are improvements over past levels and that these become goals. Best results occur when progress towards achieving these goals are charted conspicuously by the maintenance organization. These types of limits are referred to as "goal-based," see Figure 2.

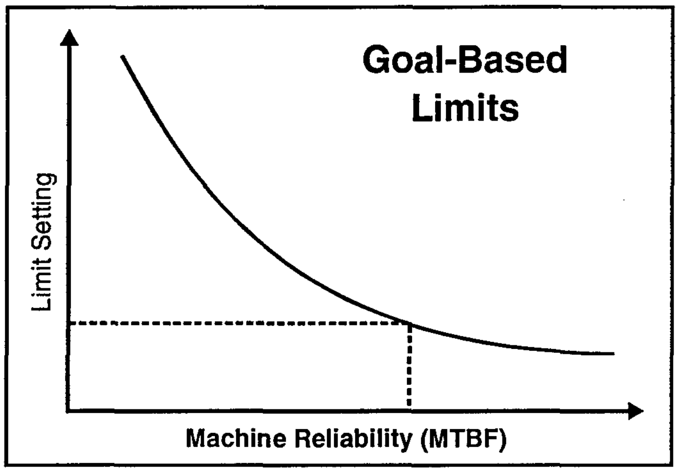


Figure 2
Goal-Based Limits Are Set For Certain Data Parameters To Proactively Improve Machine And Lubricant Reliability

In order to set a goal-based limit a level of machine reliability is identified. Again, this needs to be an improvement over previous levels. If, for instance, we use particle count as the parameter then we need to select a "target cleanliness" which is a marked improvement from before. The target cleanliness becomes the limit. In the example, if previously contaminant levels were averaging about ISO 18/15 for a hydraulic system, a limit set at 15/12 would be a goal-based improvement. A life extension of three times (MTBF) would be expected based on controlled field studies. If, on the other hand, we set a limit of 18/15 our effort is downgraded to the detection of major faults only. Goal-based limits of this type can be applied to particle counts, moisture levels, glycol levels, fuel dilution, TAN, and other common failure root cause conditions.

Another similar type of proactive limit relates to the progressive aging of the lubricant or hydraulic fluid. From the moment the oil is first put into service its physical and chemical properties transition away from the ideal (i.e., those of the new formulated oil).

For some properties the transition may be extremely slow but for others it can be abrupt and dynamic. Limits keyed to the symptoms of lubricant deterioration are referred to as "aging limits," see Figure 3. They are designed to signal the need for a well-timed condition-based oil change and are usually pegged to the depletion of additives and the thermal/oxidative degradation of the base oil.

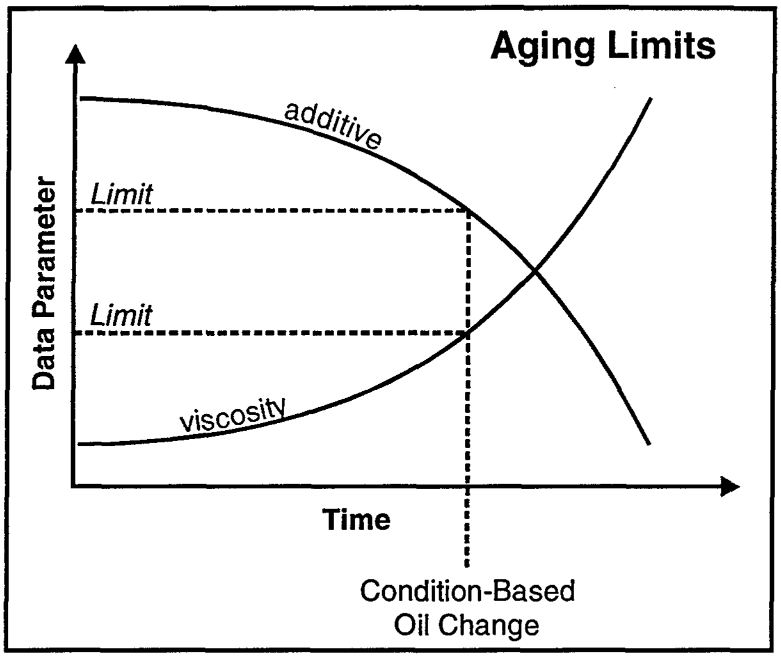


Figure 3
Aging-Limits Are Keyed To Degrading
Additive And Base-Stock Properties

In order to properly set aging limits the new lubricant must be analyzed to reveal its physical and chemical properties. This will become the oil's "base signature." Care must be taken to insure that the new oil is analyzed using the same test procedures and instruments that will be used to analyze the used oil. Under no circumstances should these "base signature" properties be simply lifted off the lubricant's spec sheet as provided by the supplier. Instruments and test methods vary substantially and new oils are approved if their properties fall within a tolerance range.

For instance, ISO viscosity grades vary plus/minus ten percent from a nominal center point (grade). This means that a VG 68 lubricant would be "in grade" from 61 to 75 centistokes (cSt). This is too much variance for 68 centistokes to serve as a proper baseline. However, if the actual viscosity of a specific lubricant was measured and found to be 64 cSt then a precise baseline is now available against which the used oil can be trended. Aging limits can be effectively applied to such parameters as TAN, TBN, viscosity, RBOT, emission spectroscopy for additive elements, FTIR (for oxidation, nitration, & sulphation), and dielectric constant.

Aging limits often follow trendable data patterns, i.e., they trend steadily in the direction of the limit. The actual time to limit might be predicted by linear or non-linear regression; a feature in some oil analysis software products. For instance, the following equation might be applied to estimate the remaining useful life of a turbine oil using Rotating Bomb Oxidation Test (RBOT):

$$\text{Percent remaining oxidative life of oil} = \frac{\text{RBOT used oil}}{\text{RBOT new oil}} \times 100$$

Lower aging limits are generally set for additive depletion, RBOT life, and TBN. Upper limits are set for dielectric constant, TAN, and FTIR for oxidation, sulphation, and nitration trends. And both upper and lower limits should be set for viscosity. The table in Figure 4 shows some example limits for both goal-based and aging parameters.

Goal-Based Limits (upper)			Aging Limits		
	Caution	Critical		Caution	Critical
Cleanliness	14/11	16/13	Viscosity	+5%	+10%
Dryness	200	600	RBOT	-30%	-60%
TAN	0.2	0.4	FTIR-Ox	0.3	1.0
Fuel	1.5%	5%	Zinc	-15%	-30%
Glycol	200 ppm	400 ppm	Calcium	-10%	-20%
Soot	2%	5%	TBN	-50%	-75%

Figure 4
Example Goal-Based and Aging Limits

Other Limits are More Predictive: Predictive limits are set to signal the presence of machine faults or abnormal wear conditions. They are aligned with the goals of predictive maintenance, i.e., the early detection of machine failure symptoms as opposed to failure root causes (proactive maintenance). In oil analysis, a proper predictive limit set to the correct parameter has many advantages over other predictive maintenance technologies. Specifically, it offers reliable incipient fault detection, spanning a wide range of machine failure modes. It is seer-like in that it has the ability to forecast a future event. As compared to vibration analysis for instance, the time-based detection window using ferrous density analysis has been demonstrated to exceed 15 times for common gear boxes failures.

Rate-of-change limits are generally identified as predictive. These are set to a property that is being progressively introduced to the oil, such as wear debris. The add rate (change) might be calculated per unit time, for instance ppm iron per 100 hours on oil. When the parameter's value is plotting against time the rate-of-change (add rate) equates to the current slope of the curve. As an alternative to representing rate-of-change, slope can be quantified by dividing rise by run for a fixed period of time (see Figure 5). The

linear trends also points to the approximate time interval remaining before a level-type limit is exceeded. Unlike level limits however, rate-of-change limits ignore the absolute value of a data parameter, emphasizing instead the speed (rate) at which the level is changing.

This can be best illustrated by an example. Suppose for a given machine, such as an industrial gear unit, iron is typically introduced to the oil at roughly 5 ppm per month. The first month after an oil change the iron shows 5 ppm, the expected level. After the second month the iron shows 10 ppm, again this is expected (5 + 5). The same holds for the end of the third month when 15 ppm is reported. The add rate of 5 ppm per month remains uninterrupted. However, by the end of the fourth month the unexpected result of 50 ppm is obtained. The computer software shows this as a critical. The reason is not due to the fact that 50 ppm in a gear lube signals abnormal wear. In fact this is a rather common iron concentration in gear oils. However, the alarm is responding to the rate at which the iron concentration changed in the last month of service (35 ppm instead of the expected 5 ppm). Had rate-of-change limits not been applied this exception might not have been reported.

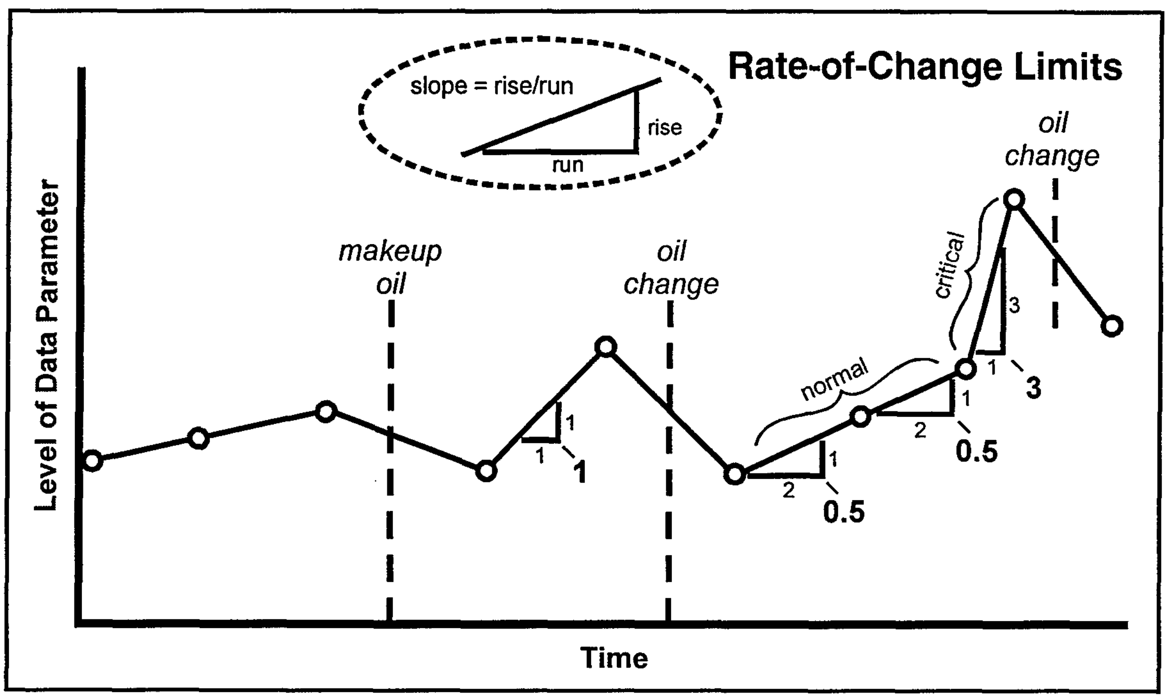
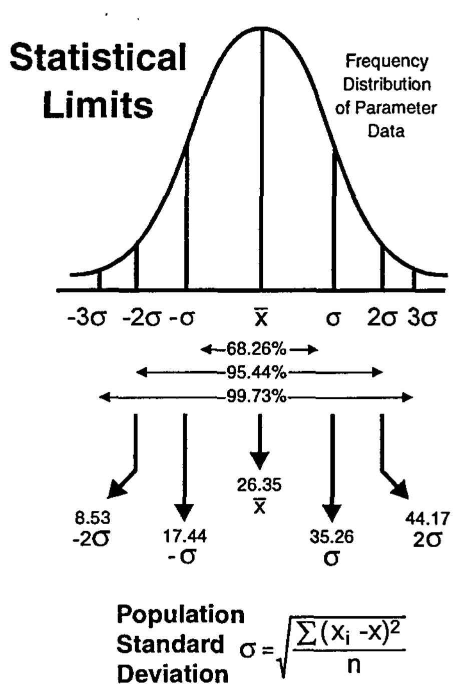


Figure 5
Using Rate-Of-Change Limits (rise/run) Must Be
Calculated For The Trending Data Parameter

The use of rate-of-change limits is well suited for wear debris analysis but can be used for other parameters as well. Examples of where it is commonly applied include particle

counts, elemental wear metals, ferrous density analysis (DR, PQ 90, Wear Particle Analyzer, ferrous Contam-Alert), TAN, and RBOT. It should be noted that multiple limit strategies can be used for single test parameters, i.e., where rate-of-change limits are applied so too are level limits (aging, proactive, and statistical).

Statistical Limits are Predictive as Well: For many years statistical limits have been used successfully in oil analysis. The practice requires the availability of a certain amount of historical data on the target parameters (see Figure 6). A population standard deviation is calculated. Upper limits are then set relating to the number of standard deviations (sigmas) above the sample population average. Many analysts put a caution at one or two sigmas and a critical at two or three sigmas. When one sigma is exceeded this means that the value from the test result exceeds 68 percent of historical samples. A result that alarms at two sigmas exceeds 95 percent of historical data. Three sigma exceedance corresponds to of 99.7 percent of the database.



Example: Historical Data of Iron Levels After 300 Hours on Oil				
24	33	39	14	9
36	28	24	22	50
17	20	18	28	44
21	15	35	30	20

Average = $\bar{x}$ = 26.35 ppm
Sigma (σ) = 8.91

Example Limits

Hours on Oil	Caution $\bar{x} + \sigma$	Critical $\bar{x} + 2\sigma$
300	35 ppm	44 ppm
500	57 ppm	70 ppm
1000	104 ppm	121 ppm

Figure 6
Statistical Limits Are Keyed To Historical Oil Analysis Trends

Many commercial laboratories have large repositories of data spanning numerous machine types and models. These data permit the relatively easy calculation of national averages and corresponding population standard deviations (sigmas). In some cases the data can be conveniently sorted according to industry and application. These same databases can be used to assist in the setting of rate-of-change limits as well. Typical applications of statistical limits include elemental analysis of wear metals, ferrous density analysis (DR, PQ 90, etc.), and other common predictive oil analysis measures.

It is well known that many machines exhibit highly individual characteristics. They might trend high or low when compared to national averages. Data from a machine that is a low reader might not alarm early enough when national averages are used as the statistical base (false negative). Likewise, when a high reader is encountered (potential false positive), it may be well advised to adjust the statistical limit accordingly, or simply rely more heavily on rate-of-change limits.

Dealing With Data Noise: Data noise can mask or distort the target data parameter (and trend) often making it nearly invisible to detection. And, when data noise exists it can inhibit the ideal placement of certain alarms and limits. A machine that normally has a high level of wear particles in its lubricating oil is a good example. These particles do not represent current wear activity but are an accumulation of historical wear, possibly going back many months. This is a common situation when course filters or no filters are in use. This high concentration of wear particles constitutes noise for an oil analysis program.

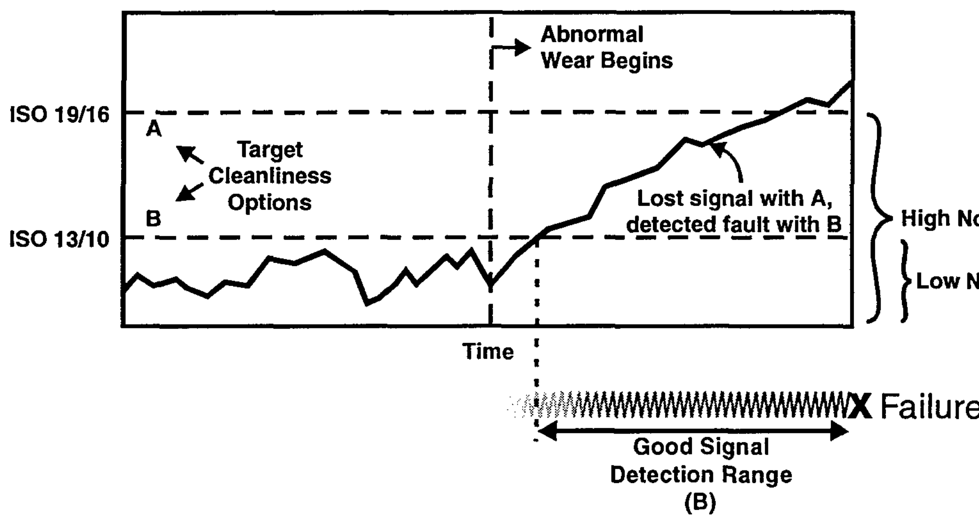


Figure 7
Clean Fluids Help Provide Improved Fault Detection Sensitivity

While the target signal (data) is current wear levels, these particles may be extremely difficult if not impossible to measure when they are mixed indiscriminately with historical wear debris. This equates to low signal-to-noise ratio. Crudely stated the fault signal is getting lost in the sauce. This situation is illustrated in Figure 7. When particle concentrations are controlled to an ISO 19/16 fault detection is poor. By comparison, the ISO 13/10 fluid translates to high-resolution detection, i.e., high signal-to-noise ratio. A similar problem occurs with infrared spectroscopy when weak absorption signals are lost due to inaccurate reference spectra and the presence of interfering materials in oil.

Summary: With the current trend of users taking control of the their oil analysis programs there has been a surge of interest in education. This has recently lead to an STLE (Society of Tribologist and Lubrication Engineers) committee being formed to offer oil analysis certification levels. While oil analysis education is often aimed at data interpretation it is no less important in the area of limit setting. In fact, limit setting and data interpretation are co-mingled activities. When oil analysis limits are properly set and the correct tests are performed at the right frequency, data interpretation is easy and efficient.

The strategic use of goal-based and aging limits enables proactive maintenance to be carried out at the highest level. Likewise, when rate-of-change and statistical limits are deployed, the benefits of early fault detection are achieved. The combination of these limit-setting strategies affords the broadest and most effective protection for the plant equipment and its lubrication assets. For more detailed information on how to set and use oil analysis limits contact the author at Noria Corporation, 2705 E. Skelly Dr., Suite 305, Tulsa, OK 74145.

References:

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